

A Case Study in All-Digital HD AM Broadcasting: Refinements, Performance Tests, and Lessons Learned

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Abstract – WWFD (820 kHz, Frederick MD), commenced operations as the first AM broadcast station to transmit using the HD Radio MA3 all-digital AM mode full-time, on July 16th, 2018. While initial performance met expectations in terms of coverage, a transmission problem occurred: the secondary and tertiary carriers were not forming correctly and were suffering from excessive bit-error losses. An inadequate switching frequency in the transmitter's Pulse Duration Modulator (PDM) had led to excessive noise in the carriers and increased spectral regrowth in the RF signal, a problem that was resolved by a transmitter replacement. A further refinement to the transmission system was made by adding a phase rotation network to the Day antenna, achieving Hermetian symmetry. With the antenna system optimized, adaptive precorrection techniques were employed in the transmitter to minimize spectral regrowth and improve signal robustness and receiver acquisition time. New drive tests were conducted. Power measurement methods regarding MA3 transmissions were explored, as they must be performed in a different manner than with standard analog AM transmissions. Additionally, a Supplemental Program Service (SPS) channel was tested for the first time. Finally, some operational "lessons learned" are presented.

Background

WWFD transmits 4.3 kW non-directional from a single series-fed tower during the daytime, and at night utilizes two series-fed towers as a directional "end-fire" configuration to form a cardioid pattern, with a null toward Dallas, TX (protecting WBAP). Nighttime power authorization is 460 watts. The antenna system underwent significant rehabilitation and upgrading in 2018 in order to achieve the bandwidth and linearity required to pass an all-digital AM signal [1]. A "rule of thumb" to achieve adequate antenna performance for digital AM operations is for the system to have a 1.4:1 Standing Wave Ratio (SWR) over the required passband (20 kHz for all-digital AM).

At the start of all-digital operations in July 2018, a significant improvement in both fidelity and coverage area over the station's analog operations occurred, but receivers were not decoding stereo audio and HD Radio images, and it took a longer-than-predicted time for these radios to lock onto the signal (5-6 seconds on average). These problems suggested that an examination of the transmitters was required, as test radios were exhibiting the same behavior with the transmitters operating into a dummy load. It was felt that additional antenna optimization could improve receiver acquisition time and signal robustness, and was addressed after the resolution of some unrelated transmitter issues. With the entire transmission system optimized, attention could then be focused on power measurement, documenting coverage, and enhancing the listener experience to best facilitate the widespread adoption of all-digital AM HD Radio broadcasting.

Transmitter Issues

One of the first observed issues upon commencing all-digital operation was the inability to transmit the secondary and tertiary carriers of the MA3 waveform (see Figure 1). Additionally, fast-acquisition information (contained within the PIDS carriers, subcarrier index ± 27 in Figure 1) was not being decoded by receivers with enough reliability to allow receiver lock within one frame (<1.5 seconds). Since the antenna system at WWFD had been broadbanded to pass the MA3 waveform, an examination of the transmitters themselves was required.

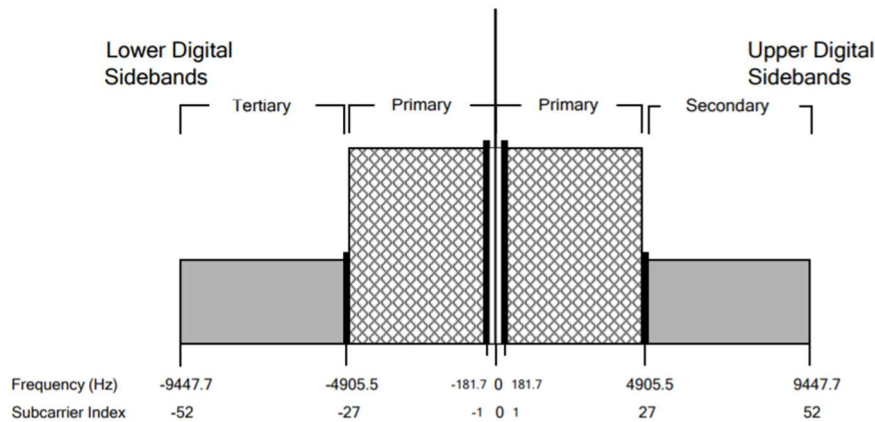


FIGURE 1: THE MA3 WAVEFORM [2].

An exciter generating the MA3 waveform has two outputs: magnitude and phase. If the exciter is external to the transmitter, its magnitude output connects to the audio input of the AM transmitter, and the phase output is connected to the external oscillator input. If the exciter is internal to the transmitter, the user does not see these connections but the inputs are functionally the same. The magnitude component of the MA3 signal has the potential to be distorted by the modulator section within the transmitter.

Contemporary AM broadcast transmitters, both analog and digital, use Pulse Duration Modulation (PDM), a brief overview of which is given by Welton and Stanley [3]. It is stressed that in order to comply with the Nyquist theorem, PDM frequencies are typically between 60-80 kHz for analog transmitters and 140-180 kHz for those implementing the hybrid mode of HD Radio technology. (Additionally, a common approach to improving the spectral mask is to use polyphase PDMs, which results in improved noise cancellation.) The baseband component of the hybrid (MA1) magnitude signal contains useful information up to a frequency of approximately 60-70 kHz (see Figure 2, top left). The baseband component of the MA3 magnitude signal contains useful information up to a frequency of approximately 100-110 kHz, which renders some PDM designs inadequate for core and enhanced MA3 transmission (see Figure 2, top right and bottom). The higher frequency components in the baseband signal contain the information to be encoded in the enhanced (secondary and tertiary) carriers, which, when run through a PDM with a frequency of 140-180 kHz, results in the scrambling of the signal constellations for those carriers. It is likely that the signal constellations of the primary carriers will be degraded as well, due to both the inadequate sampling of these carriers and the self-interference caused by the improperly-formed secondary and tertiary carriers.



FIGURE 2: THE MAGNITUDE COMPONENT OF THE MA1 (TOP LEFT) AND MA3 (TOP RIGHT) WAVEFORMS FROM 0-200 KHZ, AS VIEWED ON A SPECTRUM ANALYZER. BOTTOM: THE EQUALIZER FREQUENCY RESPONSE OF THE WWFD NX-5 TRANSMITTER FOR MA3.

The original main transmitter for MA3 operation at WWFD was a Broadcast Electronics AM-6A, which uses a 5-phase PDM. It provides an effective sample rate in the range necessary as specified by Welton and Stanley [3] for hybrid (MA1) operation, having a PDM rate (measured with a frequency counter) of approximately 152 kHz. While this transmitter is used across the industry to broadcast in the MA1 mode, using it for MA3 implementation has proven problematic. The signal constellation for the primary carriers is not tightly formed (see Figure 3, top). This problem is more evident upon examination of the PIDS carriers (see Figure 3, center). One of the functions of these carriers is to flag the transmit mode as MA3, upon which the receiver (lacking an analog fallback) is programmed to immediately output decoded audio (within one frame or approximately 1.5 seconds - i.e. “fast acquisition”). PIDS carrier distortion is the likely cause of the lack of such “fast acquisition” in receivers, resulting in a lock time of about 3 frames (approximately 5-6 seconds). Looking at the signal constellation for the secondary and tertiary carriers (see Figure 3, bottom), it is evident that no useful information is being successfully transmitted. As a result, the secondary and tertiary carriers were turned off, and the AM-6A is currently in service as an MA3 Core-only transmitter. The noise produced by the undersampling adversely affects the RF emissions mask of the transmitter, well in excess of the NRSC-5 mask (see Figure 4, left) but still within the limits of the NRSC-2 mask, which is the current FCC standard for determining legal emissions.

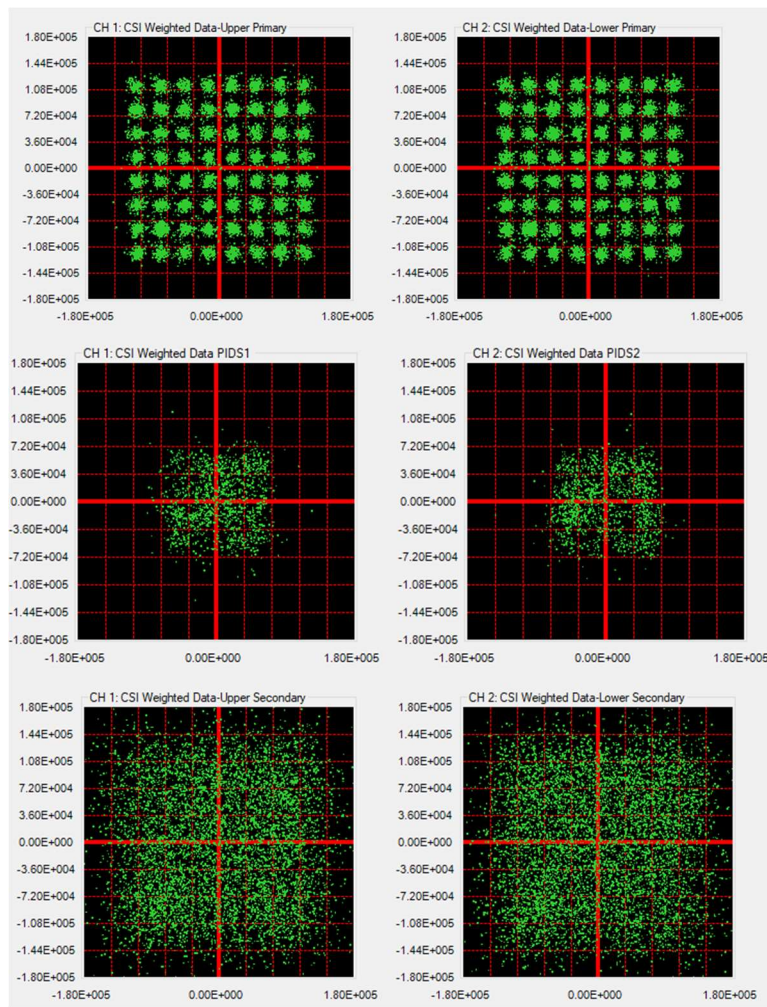


FIGURE 3: SIGNAL CONSTELLATION PLOTS OF THE ORIGINAL MAIN TRANSMITTER WITH INADEQUATE PDM RATE. TOP: UPPER AND LOWER PRIMARY CARRIERS. CENTER: PIDS CARRIERS. BOTTOM: SECONDARY AND TERTIARY CARRIERS.

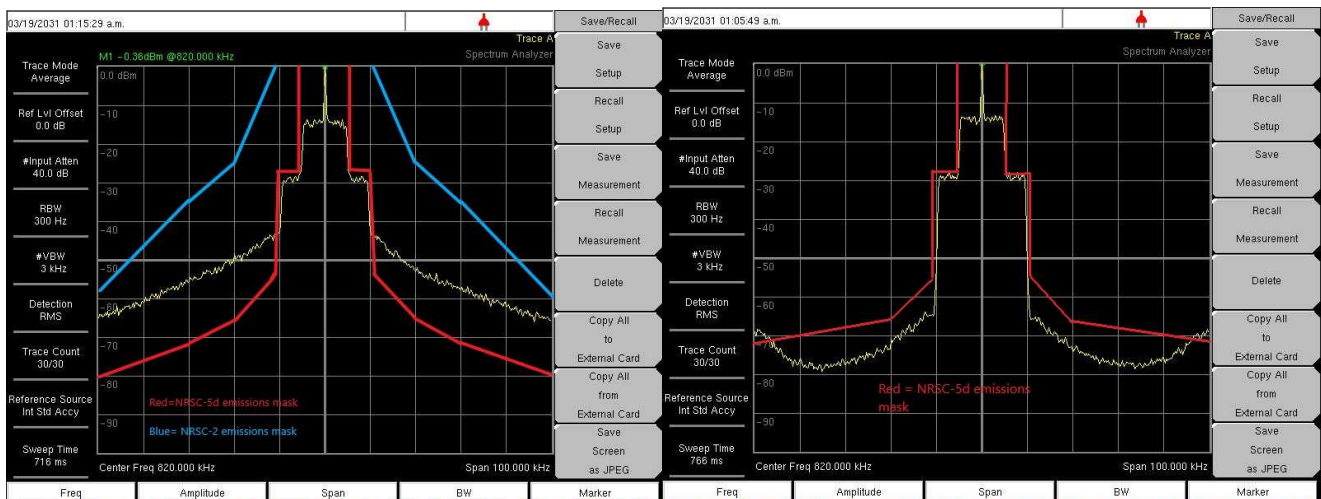


FIGURE 4: SPECTRUM ANALYZER PLOTS OF THE ORIGINAL MAIN TRANSMITTER (LEFT), AND THE REPLACEMENT TRANSMITTER (RIGHT) WITH ADEQUATE PDM SAMPLE RATE.

In addition to examining the constellation diagram, a second way to examine the quality of transmission is through a Fast Fourier Transform (FFT - see Figure 5, left). Signal level (in dB) versus FFT bin number (which corresponds to frequency) is plotted. The primary carriers are visible on the opposing edges of the X axis, but the secondary and tertiary carriers (turned on for this measurement) are indistinguishable from the noise generated by the transmitter. Such noise is high enough to reduce the Signal to Noise Ratio (SNR) of the primary carriers. If the PDM rate were fast enough for MA3 operation, a low SNR would be indicative of insufficient headroom in the power amplifiers. The Peak to Average Power Ratio (PAPR) of the MA3 waveform is approximately 9.8 dB [4], as opposed to 6 dB for standard amplitude modulation. Reducing the output power of the transmitter to a point where the amplifiers can deliver a sufficient SNR for all carriers would then be required. Current Crest Factor Reduction (CFR) techniques can reduce the PAPR to approximately 8.2 dB without significantly compromising signal robustness, leading to higher digital power output capacity. Since the PDM of the AM-6A does not have a sufficiently high sample rate, power reduction did not yield an improvement in the SNR. Once the PDM issue is resolved, transmitter power output can be revisited.

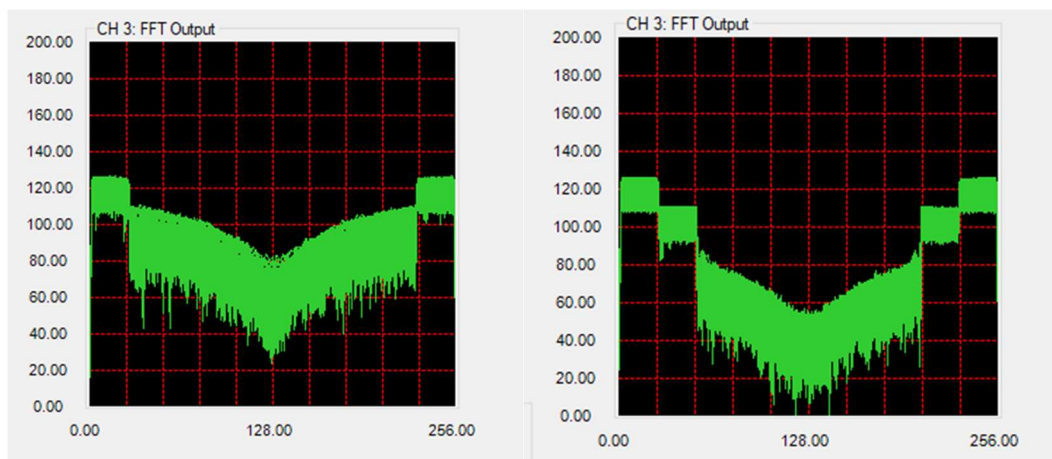


FIGURE 5: FAST-FOURIER TRANSFORMS (FFTs) OF THE ORIGINAL MAIN TRANSMITTER (LEFT), AND THE REPLACEMENT MAIN TRANSMITTER (RIGHT) WITH ADEQUATE PDM SAMPLE RATE.

Attention then turned to the Harris Gates Five auxiliary transmitter to examine its capabilities for MA3 operation. The Gates Five uses a four-phase PDM, with a sample rate of 60 kHz. While this violates Nyquist, a 6 dB improvement in the spectral mask was achieved, likely due to more headroom in the amplifiers. A further problem was revealed in the VSWR detection circuitry, where the MA3 waveform caused the transmitter to step down to its night power preset (460 watts). After contacting the manufacturer, it was determined that a field modification to the transmitter was beyond the ability of station personnel (and would not be supported), and so the transmitter was abandoned. It should be noted that the Harris DX series, the successor to this transmitter, does not have the VSWR foldback issue seen on the Gates series. With its higher sampling rate, it has been used to successfully implement MA3 during previous experiments at other facilities [5].

With the two existing transmitters at WWFD unable to produce the full (Core + Enhanced) waveform, a Nautel NX-5 transmitter was installed. This transmitter utilizes a 6-phase PDM, and a sample rate (measured with a frequency counter to be approximately 230 kHz) that easily accommodates the frequency components of the full MA3 baseband signal. An examination of the signal constellation of the primary carriers (see Figure 6, top) and the PIDS carriers (see Figure 6, center) show near-perfect formation, which results in fast receiver acquisition (<1.5 seconds). This is a highly desirable feature to have successfully implemented in MA3, being that there is no analog transmission for instant acquisition or receiver fallback. An examination of the secondary and tertiary carriers (see Figure 6, bottom) also yields well-formed carriers. Features of MA3 incorporated into these carriers, such as

album artwork, stereo audio, and enhanced Emergency Alert System (EAS) alerts (whose information is also contained within the PIDS carriers) are now being successfully transmitted. The secondary and tertiary carriers are slightly less-defined than the primary carriers on the signal constellation plots, likely caused by the implementation of CFR within the transmitter. An examination of the FFT (see Figure 5, right) shows well-defined primary, secondary, and tertiary carriers, with the transmitter noise below that of all carriers. These attributes demonstrate both adequate PDM frequency and amplifier headroom. The FFT plot, like the spectrum analyzer plot (see Figure 4, right), reveals a properly generated MA3 waveform. It should be stressed, however, that signal constellation plots are preferred for transmitter adjustment. Tight “clouds” corresponding to each level of the 64QAM (primary, secondary, and tertiary) carriers and the 16QAM (PIDS) carriers are observed when optimal tuning is attained. With the transmitter confirmed to be properly generating the full MA3 waveform, effort could focus upon further optimizations regarding the WWFD antenna system and the transmitter itself.

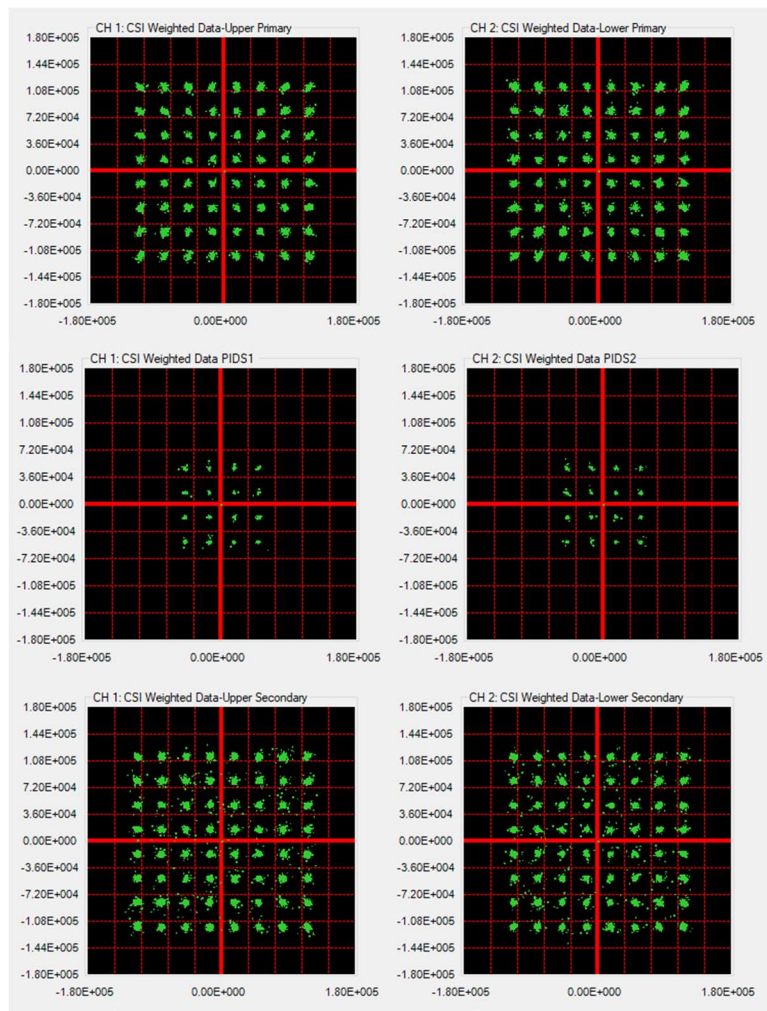


FIGURE 6: SIGNAL CONSTELLATION PLOTS OF THE REPLACEMENT MAIN TRANSMITTER. TOP: UPPER AND LOWER PRIMARY CARRIERS. CENTER: PIDS CARRIERS. BOTTOM: SECONDARY AND TERTIARY CARRIERS.

Antenna Refinements and Adaptive Precorrection

Fine-tuning the transmitter's output load (i.e. the antenna system) was the next step toward optimizing WWFD's facilities. At the transmitter amplifier output, a Smith chart for the nighttime antenna system already exhibited a form of Hermetian symmetry, with the impedance locus aligned along a constant resistance circle ("cusp right"). As a result, the night antenna requires no further optimization in order to present an optimum load to the transmitter. The daytime antenna system at the transmitter, however, had its impedance locus oriented such that its cusp faced upwards on a Smith chart. In order to achieve Hermetian symmetry, it was simplest to build a network to rotate the phase such that the impedance locus aligns with a constant conductance circle ("cusp left"). Once achieved, adaptive precorrection algorithms could be adjusted for the best spectral mask compliance.

WWFD's rebuilt Day antenna system [6] consisted of a T-network feeding the tower, with a series capacitor (located in the phasor cabinet) tuning out the excess inductance of the transmission line. At the input to the T-network at the tower, Hermetian symmetry is achieved, with the impedance locus facing "cusp left." However, the phase is rotated through the transmission line, resulting in the cusp facing upwards at the transmitter. The series capacitor does not compensate for this. In consultation with Kintronic Laboratories (Bluff City, TN), this capacitor was removed and a new T-network was installed in the phasor cabinet, performing the two functions of rotating the phase and compensating for the excess inductance in the transmission line. The network, as designed, rotates the phase 60 degrees (see Figure 7). The input branch was designed to provide additional broadbanding of the Day antenna, presenting the best possible load to the transmitter with the existing antenna system (see Figures 8-10).

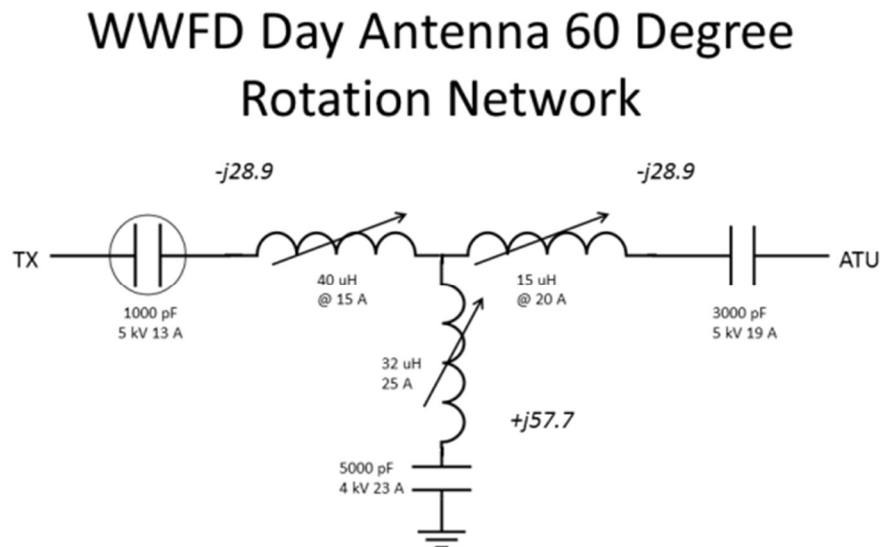


FIGURE 7: WWFD DAY ANTENNA PHASE ROTATION NETWORK.

Before phase shift network installed

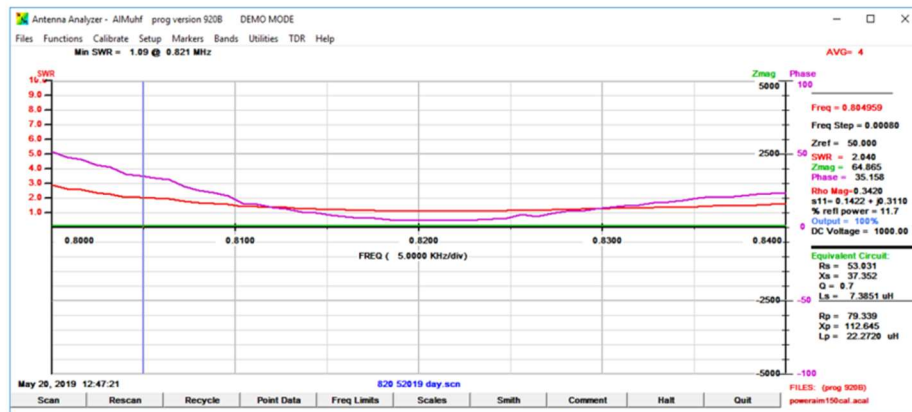


FIGURE 8: WWFD ORIGINAL DAY ANTENNA CHARACTERIZATION MEASURED AT THE MAIN TRANSMITTER.

After phase shift network installed

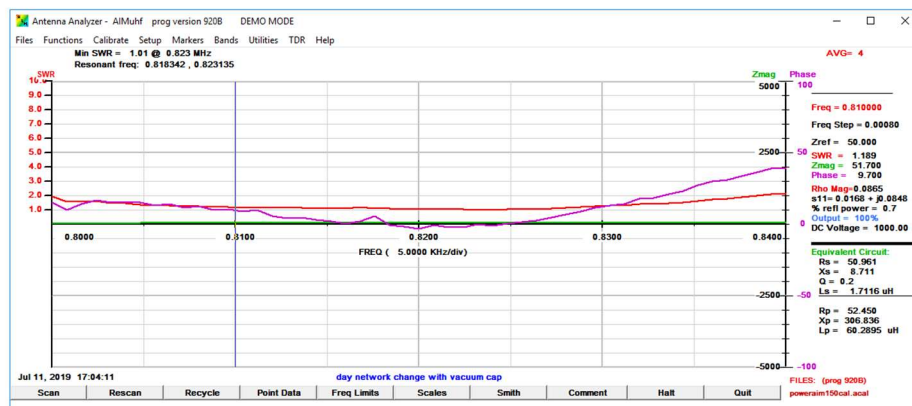


FIGURE 9: WWFD DAY ANTENNA CHARACTERIZATION WITH 60 DEGREE PHASE ROTATION NETWORK, MEASURED AT THE MAIN TRANSMITTER.

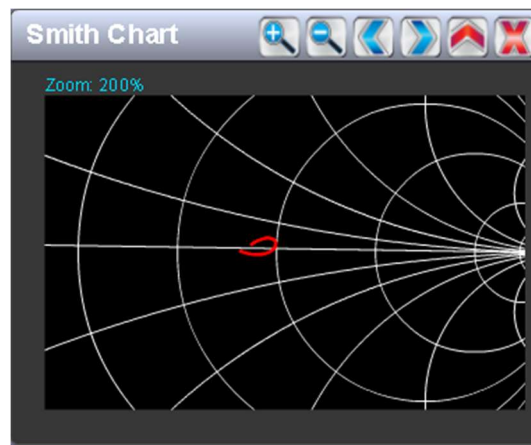


FIGURE 10: WWFD DAY ANTENNA LOAD (ROTATED) AS PRESENTED TO THE NEW MAIN TRANSMITTER.

The adaptive precorrection algorithms in the new main transmitter are optimized at the factory under ideal load conditions, hence the importance of optimizing the antenna system before any retraining of these features is begun. Adjustable/re-trainable features within the main transmitter include Magnitude-Phase Delay, AM-AM Correction, AM-PM Correction, and Envelope Equalization. The adjustment of these parameters should be performed with the goal of NRSC-5 mask compliance [7], with the understanding that significantly deviating from factory-set parameters can adversely affect reception in fringe coverage areas. In general, it is recommended to alter the precorrection settings such that they do not significantly change the frequency response of the magnitude component signal, as seen on the transmitter's user interface (see Figure 2, bottom). For imperfect antenna loads, strict NRSC-5 mask compliance (when measured at the transmitter's monitor port) may not be possible in areas outside of the passband of the antenna system, as the VSWR is often extremely high at these frequencies, whereas at those same frequencies a low VSWR exists when operating into a dummy load (and NRSC-5 compliance is achieved). Given the relatively narrow passband of a typical AM antenna system, emissions mask compliance when measured off-air can still be achieved, and has been proven for WWFD through independent measurements.

Drive Testing

The first round of drive testing at WWFD occurred during the summer of 2018 [6], with the original transmitter running the core-only mode of MA3 (due to the limitations of its PDM). A second round of tests was conducted in the summer of 2019 with the full (core and enhanced – i.e., primary, and secondary/tertiary carriers) mode of MA3. Daytime in-vehicle reception of the full MA3 signal was consistently observed to the predicted 0.5 mV contour (see Figure 11, top). Beyond this contour, only the core (primary) carriers are received, until approximately the predicted 0.1 mV contour. This translates to a user experience of stereo audio and album artwork within the 0.5 mV contour, and monaural audio with only track data (title, artist, and album) possible to the predicted 0.1 mV contour. It should be noted that depending upon co-channel skywave interference during critical hours (defined by the FCC as two hours after sunrise and two hours before sunset), degraded reception conditions were observed on some days beyond the 0.5 mV contour.

Nighttime reception tests have yielded less predictable results. A “rule of thumb” is that whenever the analog audio signal achieves an SNR of 20 dB, a corresponding MA3 signal will decode. This translates to (in a worst-case scenario) approximately one-half the value of the predicted Nighttime Interference Free (NIF) contour. For WWFD, the predicted NIF is 10.8 mV; therefore, the “half-NIF” is 5.4 mV. At the time of nighttime pattern change when little co-channel skywave interference is present, groundwave coverage to the predicted 0.5 mV contour was observed (although the secondary and tertiary carriers fluttered toward the edge of this coverage due to propagation conditions and adjacent-channel interference). Coverage tends to retreat later in the evening, sometimes all the way back to the “half-NIF” contour. The summer 2019 nighttime tests (see Figure 11, bottom) showed more extensive coverage than tests conducted in December 2019 (see Figure 12), as skywave interference in winter tends to be more prevalent at identical times of the evening (approximately 9 PM through midnight for each test). The nighttime drive tests demonstrate that the “half-NIF” contour of a station is a predictable metric of reliable nighttime coverage for an MA3 signal.

HD RADIO TECHNOLOGY



WWFD-AM DAYTIME PATTERN – ALL DIGITAL

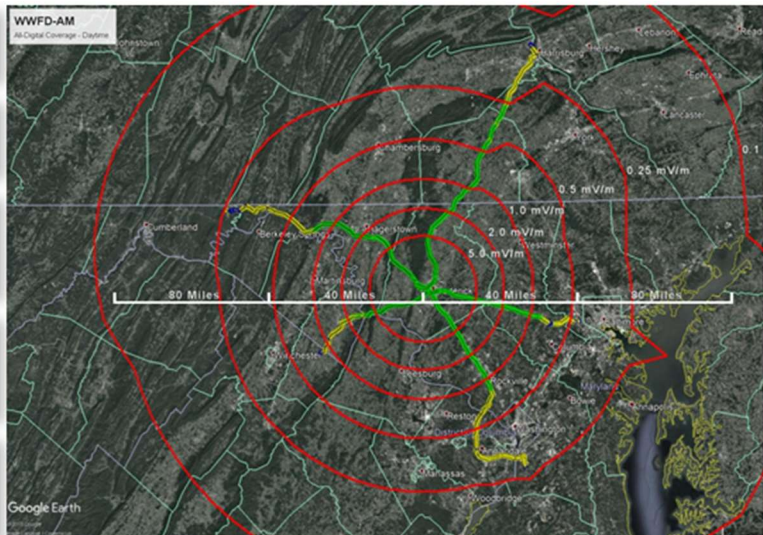
5.0 / 2.0 / 1.0 / 0.5 / 0.25
mV/m contours shown

All-digital signal fills in 0.5 mV/m
protected daytime contour

Class: B – 820 kHz
Daytime Power: 4.3 kW
Day – Non-Directional

Enhanced Mode = Green
Core Only Mode = Yellow
Mute Mode = Blue

5.0 mV/m population = 215,124
2.0 mV/m population = 456,791
0.5 mV/m population = 2,777,722



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HD RADIO TECHNOLOGY



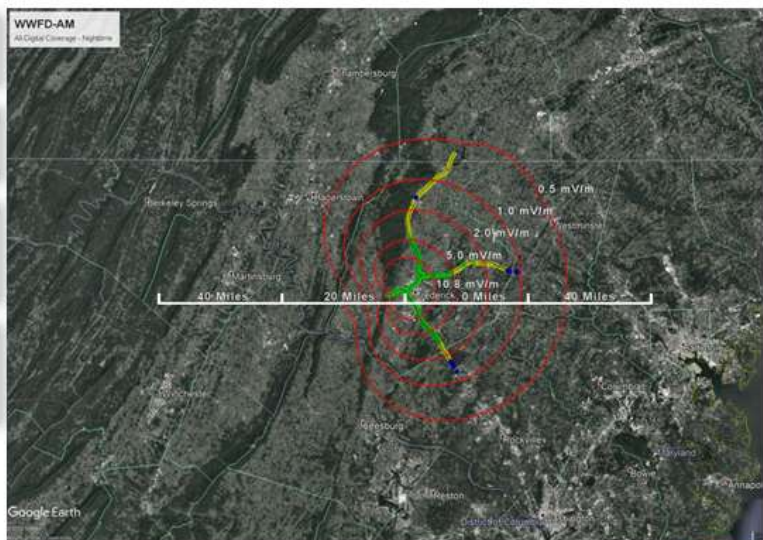
WWFD-AM NIGHTTIME PATTERN – ALL DIGITAL

10.8 / 5.0 / 2.0 / 1.0 / 0.5
mV/m contours shown

All-digital signal fills in 5.4 mV/m
“half-NIF” contour

Class: B – 820 kHz
Nighttime Power: 430 W
Day – Directional Southwest

Enhanced Mode = Green
Core Only Mode = Yellow
Mute Mode = Blue



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FIGURE 11: WWFD DAYTIME (TOP) AND NIGHTTIME (BOTTOM) DRIVE TEST COVERAGE, SUMMER 2019

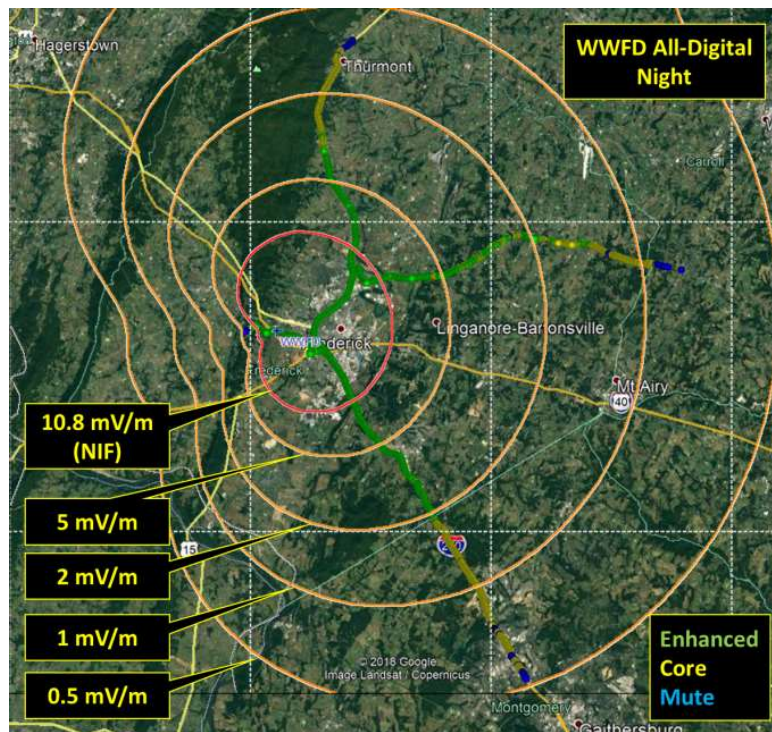


FIGURE 12: WWFD NIGHTTIME DRIVE TEST COVERAGE, WINTER 2019.

Power Measurement

Power measurement techniques currently utilized by AM stations in the United States typically are as follows:

- Base current measurement for non-directional antenna systems with a toroidal sample and a calibrated diode current meter.
- Common point and base current measurements for directional antenna systems, employing the same method above.
- Measurement at the transmitter output with a thermocouple-type RF ammeter.

The first two techniques employed above commonly use a diode detector and meter to measure the RF current. This is problematic when measuring the Orthogonal Frequency Division Multiplex (OFDM) carriers employed in MA3 transmission. The OFDM carriers utilize Quadrature Amplitude Modulation (QAM) and are random in nature, dependent solely on the information being sent. At some point, it is possible that most or all the carriers could be in phase, which would significantly raise the peak power. Conversely, it is possible that the carriers could be mostly or totally out of phase with each other, thereby reducing the power to zero. Therefore, measuring the average power is the best metric. The following methods described to measure the true RMS power have been found to be very accurate. However, all the methods described have their advantages and disadvantages. It is important to follow these steps to make sure the station is in compliance with 47 CFR 73.1590.

True RMS Power Meter

The first device used to measure average power at WWFD was an HP 437B power meter with an HP 8481A thermocouple probe, with a Delta Electronics TCT-N current transformer. The power meter and probe were calibrated by a test equipment supplier for proper operation. The transformer was placed at the output of the transmitter before the input to the tower ATU. The thermocouple probe was

attached to the current transformer, and the power meter was initialized. First, a baseline reading was obtained by operating the transmitter with an unmodulated carrier with no MA3 carriers present. At this point, the station was verified to be operating at licensed power by conventional means already employed at the station (for WWFD, common point and base current meters). Once a baseline reading was measured and the station verified to be operating at licensed power; the QAM carriers were turned on.

Typically, with the QAM carriers present, another measurement is made with the power meter. The two readings should be identical or nearly so (within 2%). If this is not the case, then the digital power output is adjusted to match the baseline reading.

The advantages of this method are:

- Accuracy (within 2%).
- Current transformer is most likely already in place for conventional power measurements.
- Flexibility, as the RF sample port on a transmitter can be used as well.
- Meter is calibrated by a professional outfit.

The disadvantages are:

- Cost of equipment, even to rent.
- A power meter is not a tool usually available to broadcasters, which may necessitate the use of a consultant to perform measurements.

Spectrum Analyzer

The device used at WWFD to perform this measurement was an Anritsu MS7213E spectrum analyzer, connected to the RF sample output of the transmitter (Nautel NX5). The spectrum analyzer was placed in channel power mode, configured to measure the channel power of the expected occupied bandwidth of the spectrum. In the case of the Anritsu, the minimum channel width allowable to be measured was 100 KHz. It should be noted that the channel power measurement averaging setting was set to RMS, not video averaging. A baseline measurement was made, once again operating the transmitter with an unmodulated carrier (see Figure 13, left). At this point, the station was verified to be operating at licensed power by existing (conventional) means.



FIGURE 13: CHANNEL POWER MEASUREMENT ON A SPECTRUM ANALYZER. NOTE THAT CH. PWR VALUES ARE NEARLY IDENTICAL FOR CW (LEFT) AND MA3 (RIGHT).

In this test procedure, once a baseline measurement is obtained, the MA3 carriers are then activated. Another measurement is made with the spectrum analyzer (see Figure 13, right). The readings should be identical or nearly so (within 2%). If there is a variance, the transmitter power output is adjusted to match the baseline reading.

The advantages of this method are:

- Accuracy (within 2%), as long as the unit is factory calibrated.
- RF sample port is available on all modern transmitters.
- Flexibility, as a current transformer can be used to make this measurement as well.
- More common than a power meter.

The disadvantages are:

- Cost of equipment, even to rent.
- Although more common than a power meter, spectrum analyzers may only be in the possession of the larger groups of broadcasters.
- Required familiarity with the equipment in order to set it up correctly.

Thermocouple-type RF Ammeter

The devices used at WWFD were a Simpson 0-15 A RF ammeter mounted on a fiberglass “J-Plug” (used for daytime power measurements) and a Weston 0-5 A RF ammeter mounted in an identical fashion for nighttime measurements. The thermocouple meters were calibrated by using a known load and RF voltage. Both are inserted into the J-Plug between the output of the tower ATU and the tower feed itself, with the smaller meter also inserted in the common point J-Plug for night measurements. All of these locations are points where current transformers for the base current and common point measurements are located. With the meter inserted into the system at appropriate locations, a baseline reading was obtained by operating the transmitter with an unmodulated carrier.

The RF ammeter readings should match the readings from the station’s preexisting metering system. Once confirmed, indicating that the station is operating at licensed power (and the thermocouple ammeters are accurate), the MA3 carriers are turned on. The RF ammeter should read the same as with an unmodulated carrier. If the preexisting base current meter is a diode detector, such as a Delta TCA-type, the reading will be slightly lower. (In WWFD’s tests, the TCA meters consistently read approximately 93% of the thermocouple ammeter readings with a transmitter PAPR of 8.2 dB – see Figures 14-15).

The advantages to this method are:

- Inexpensive.
- Common, as most stations may have these meters “on the shelf,” or they can be purchased either through a supplier of RF components or through AM antenna design/consulting firms.
- Easy to implement and read.

The main disadvantage is that the accuracy of any such meter needs to be verified, especially given the age of these out-of-production meters.

2.8 A



3.0 A



2.8 A



3.0 A



3.0 A



3.2 A



FIGURE 14: NIGHTTIME MEASUREMENTS OF COMMON POINT (TOP, LICENSED VALUE OF 3.05 A), TOWER 1 (CENTER), AND TOWER 2 (BOTTOM).

9.6 A



10.4 A



FIGURE 15: DAYTIME MEASUREMENT OF (NON-DIRECTIONAL) TOWER 2, LICENSED BASE CURRENT = 10.5 A.

All three measurement methods have proven to be accurate. The power meter and spectrum analyzer are essentially the same approach to power measurement (using the station's existing power measurement system with an unmodulated carrier as a baseline to calibrate the transmitter's MA3 output power with the additional equipment). It should be noted that if the power meter or spectrum analyzer is connected to the transmitter's RF monitor port, baseline measurements must be taken at each licensed power level, as transmitters often adjust the monitor port for each power level in order to present the correct drive level to a modulation monitor. Of the three methods outlined above, the thermocouple RF ammeter approach is preferred for accuracy (being a direct measurement that does not depend solely upon the accuracy of the station's existing monitoring system), availability, and cost.

Supplemental Program Service (SPS) Testing

Xperi Corporation has been exploring the possibility of adding an SPS channel on the MA3 waveform. The idea had been investigated prior to WWFD commencing all-digital broadcasting in July 2018. By adding a second audio channel to the MA3 signal, AM broadcast stations would be able to operate an HD2 multicast channel, much like their FM counterparts. This would open the possibility of gaining an additional FM translator (with a separate program feed) for AM stations, similar to current practice with FM stations.

Several changes were needed to add an HD2 multicast channel to the MA3 all-digital mode. On the transmit side, a new Importer configuration was created for allocation of Protocol Data Units (PDUs) to a second audio service. On the receiver side, new DSP code was written for baseband ICs. The Importer configuration was relatively simple, written by Xperi software developers in less than one day. The DSP receiver code changes required examination and testing so as to not compromise existing receiver designs in the marketplace. Once this process started, it was discovered that certain SPS designs by earlier developers had already been partially implemented. One IC had code written for an SPS channel using MA3 but was simply "commented" out. Once this code was modified in a test receiver, the baseband IC was re-flashed.

With the necessary modifications to an Importer configuration and test receiver complete, and laboratory testing successfully performed, the next step was to test an SPS channel in a real-world environment. A test configuration was loaded into the WWFD Importer/Exporter, and on December 5th, 2019, testing of the first HD2 multicast channel on an AM broadcast station began. The signal was

broadcast for several hours with no observed problems with the transmitter and all available receivers. Several commercially available receivers were also tested in the laboratory to verify performance without adverse effects. Pictures of the test receiver software show the Program Service Data (PSD) being sent via WWFD-AM HD2 (see Figure 16, left). A Station Logo (see Figure 16, right) was also transmitted. The programming on the HD2 channel was WWFD’s sister station, WTOP (Washington, DC). Further testing will be performed with the goal of a commercially available receiver in the future.

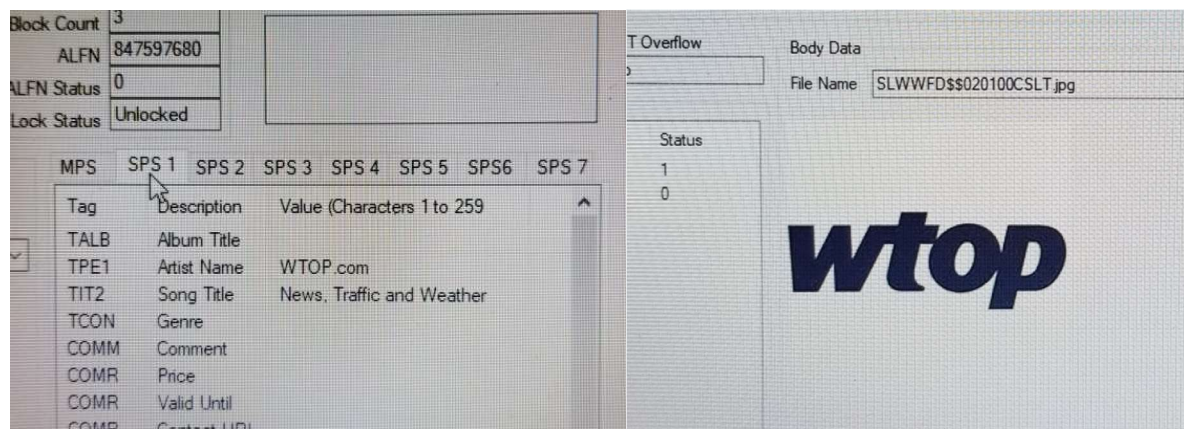


FIGURE 16: WWFD HD2 PROGRAM SERVICE DATA (LEFT) AND STATION LOGO (RIGHT) ON XPERI TEST RECEIVER.

The SPS PDUs are contained entirely within the secondary and tertiary carriers of the MA3 waveform. Therefore, it follows that the expected coverage area of an AM HD2 signal would correspond to the area in which full MA3 (core and enhanced) coverage is achieved. For WWFD, this would be the green areas of the maps comprising Figures 11-12. Once a receiver enters the core-only service area, the HD2 will disappear, and only the Main Program Service (MPS) will be available until the MA3 signal drops out entirely. Since the total effective throughput of the MA3 waveform is 40.2 kbps, creating an SPS reduces the audio bandwidth of the MPS to a point which necessitates monaural transmission for both the MPS and SPS channels (for example, about 20 kbps for the MPS and 17 kbps for the SPS, with the remainder allocated for data services).

Lessons Learned

During the course of configuring WWFD for MA3 operation, a number of “tips and tricks” were learned which may be of benefit to stations who wish to convert to all-digital AM broadcasting in the future. Achieving Hermetian symmetry at the transmitter output amplifiers, while not absolutely necessary (especially when the reflected power is sufficiently low), does appear to contribute to improved “fast acquisition” and increased robustness against momentary obstructions in mobile receivers. Either a “cusp left” or “cusp right” at the final amplifier output provides improved receiver response. It should be noted that the output networks of individual transmitters have varying phase shifts, and so a consultation with the manufacturer may be necessary in order to design an optimal phase rotation network.

Proper audio processing for the low-bitrate audio of the MA3 signal is essential for providing a pleasant listener experience. Typical AM HD processor designs have presets optimized for the analog audio portion of the standard hybrid (MA1) signal, which can sound too aggressive when used for MA3. Loudness and audio quality are not achieved via a dense asymmetric audio signal as with analog AM. An approach for processing a low-bitrate audio stream [8] should be considered. This approach often means reducing the drive level of the final clipper and relaxing the input AGC

parameters. Such an approach will ensure maximum audio fidelity and will not sound fatiguing and “grungy” to the listener.

Finally, if a transmitter with an internal AM HD exciter is used, the power supply of the Engine card should be protected by an uninterruptible power supply (UPS). Since the WWFD transmitter was not available from the factory with UPS protection, an external 5-volt power supply was modified with an adaptor cable (see Figure 17) in order to power the card from a protected power source. During a power interruption (either a momentary utility outage or an interruption caused by a transfer to generator power), transmission outages are minimized by ensuring that the Engine card does not reboot. With UPS protection, the length of the transmission interruption is only the length of the power interruption, as opposed to the interruption plus Engine reboot (often in excess of 30 seconds). Attention to the above details will help provide an improved listener experience and facilitate the adoption of MA3 transmission.

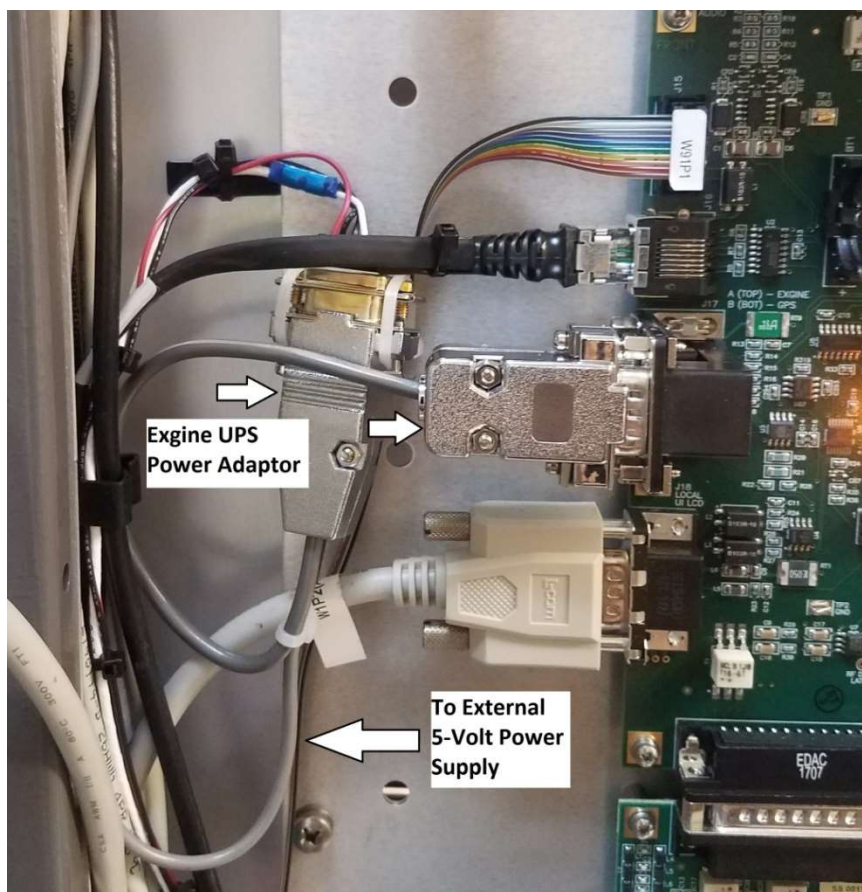


FIGURE 17: WWFD MAIN TRANSMITTER ENGINE ADAPTOR CABLE FOR EXTERNAL 5 VOLT UPS-PROTECTED POWER SUPPLY.

Discussion and Future Work

The second year of all-digital operations at WWFD has brought substantial operational improvements: fast receiver acquisition (within 1.5 seconds), stereo audio, visual metadata, enhanced EAS alerts identical to those on FM HD stations, an AM HD2 multicast channel as proof-of-concept, and a better understanding of the digital station's operating parameters (power measurement) and coverage area. Such improvements have demonstrated both aural and visual parity with other broadcast services in a typical vehicle entertainment system: FM HD Radio, satellite, and streaming audio. Trends in receiver

design are converging towards tuning by visual metadata: a listener would simply select the logo of an available service in order to choose an audio program [9]. MA3 transmission allows AM broadcast stations to deliver a richer and more pleasant user experience (than with standard analog transmission), and retain a prominent position in the vehicle “dashboard of the future.”

With regard to future tasks, tests under different noise environments (indoors, utility lines, electrical storms, et cetera) should be conducted to attempt to systematically quantify the effects of these environmental factors upon reception. Such information would allow stations to better understand their marketable signal coverage area for different types of listeners.

Testing with transmitter manufacturers regarding PDM and amplifier systems should be conducted in order to explore the possibility of modifying existing transmitters that are currently inadequate for MA3 use. The possibility of field or factory modifications of existing transmitters will facilitate the adoption of MA3 operation.

Finally, testing and refinements of AM SPS channels will be explored. Such efforts may encourage MA3 adoption, primarily through the possibility of a separately programmed FM translator from the MPS.

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